

# CLAIMS

1. An objective lens for an optical disk comprising a single lens having aspheric surfaces on both sides and focusing light beams into a point image through first and second optical disk substrates each having a different thickness,

at least one of the aspheric surfaces comprising two regions including an inner circumference region at an inner side of a circular aperture having an optical axis as a center and an outer circumference region located at an outer side with respect to the inner circumference region, the aspheric profile of the outer circumference region correcting a spherical aberration with respect to the first optical disk substrate which has a smaller thickness than the second optical disk substrate, and the aspheric profile of the inner circumference region correcting a spherical aberration with respect to the second optical disk substrate, the outer circumference region and the inner circumference region are in contact with each other at the boundary therebetween with a difference in level in the direction of the optical axis,

wherein the objective lens satisfies the following relationships (1) to (4);

$$t_1 < t_2 \quad (1)$$

$$0.05 < TW < 0.12 \quad (2)$$

$$0.38 < NA_1 < 0.46 \quad (3)$$

$$0.1 < p(n-1)/\lambda < 0.6 \quad (4)$$

wherein  $t_1$  denotes a thickness of the first optical disk substrate,  $t_2$  denotes a thickness of the second optical disk substrate,  $NA_1$  denotes a NA of the objective lens at the aperture of the inner circumference region,  $TW$  denotes a wavefront aberration when light beams are focused through the first optical disk substrate (unit is  $\lambda$ : rms),  $n$  denotes a refractive index of the objective lens at the wavelength of a light source when data of the first optical disk is reproduced,  $p$  denotes a difference in level between the inner circumference region and the outer circumference region in the direction of the optical axis; and  $\lambda$  denotes a wavelength of the light source when data of the first optical disk is reproduced.

2. The objective lens for an optical disk according to claim 1, wherein the third order spherical aberration component  $S_3$  of the wavefront aberration is approximately 0 when light beams are focused through the first optical disk substrate.

3. The objective lens for an optical disk according to claim 1, wherein a fifth order spherical aberration component  $S_5$  (unit is  $\lambda$ :rms) of the wavefront aberration satisfies the following relationship (5) when light beams  
5 are focused through the first optical disk substrate.

$$-0.03 < S_5 < 0.03 \quad (5)$$

4. The objective lens for an optical disk according to claim 1, wherein the thickness  $t_3$  of the optical disk substrate satisfies the following relationship  
10 (6), when the aspheric profile of the inner circumference region is optimized so that the spherical aberration is corrected with respect to the thickness  $t_3$  of the optical disk substrate.

$$0.8 < t_3 < 1.2 \quad (6)$$

15 5. The objective lens for an optical disk according to claim 1, wherein the cross section of the portion having the difference in level between the inner circumference region and the outer circumference region has a circular arc profile.

20 6. The objective lens for an optical disk according to claim 1, which is formed by glass molding or plastic molding.

7. An objective lens for an optical disk comprising a single lens having aspheric surfaces on both sides and focusing light beams into a point image  
25 through first and second optical disk substrates each having a different thickness,

at least one of the aspheric surfaces comprising three regions including of an inner circumference region at an inner side of a circular aperture having an optical axis as a center, a middle region located at an outer side with  
30 respect to the inner circumference region and surrounded by another circular aperture that is located at an outer side of the circular aperture, and an outer circumference region located at an outer side with respect to the middle region, the aspheric profiles of the inner circumference region and the outer circumference region correcting a spherical aberration with respect to the first  
35 optical disk substrate which has a smaller thickness among the first and second optical disk substrates, and the aspheric profile of the middle region correcting a spherical aberration with respect to an optical disk substrate

having a thickness that is larger than any of the first and second optical disk substrates, wherein the objective lens satisfies the following relationships (7) and (8);

$$0.35 < NA2 < 0.43 \quad (7)$$

5  $0.03 < NA3 - NA2 < 0.1 \quad (8)$

wherein NA2 denotes a NA of the objective lens at the boundary between the inner circumference region and the middle region, and NA3 denotes a NA of the objective lens at the boundary between the middle region and the outer circumference region.

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8. The objective lens for an optical disk according to claim 7, wherein the thickness t4 of the optical disk substrate satisfies the following relationship (9), when the aspheric profile of the middle region is optimized so that the spherical aberration is corrected with respect to the thickness t4 of the optical disk substrate.

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$$1.4 < t4 < 2.0 \quad (9)$$

9. The objective lens for an optical disk according to claim 7, wherein either the boundary in which the inner circumference region is connected to the middle region or the boundary in which the middle region is connected to the outer circumference region does not have a difference in level.

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10. The objective lens for an optical disk according to claim 7, wherein the cross section of the portion having a difference in level between the inner circumference region and the middle region or the cross section of the portion having a difference in level between the middle region and the outer circumference region has a circular arc profile.

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11. The objective lens for an optical disk according to claim 7, which is formed by glass molding or plastic molding.

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12. An objective lens for an optical disk comprising a single lens having aspheric surface on both sides and focusing light beams into a point image through first and second optical disk substrates each having a different thickness,

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at least one of the aspheric surfaces comprising three regions including of an inner circumference region at an inner side of a circular aperture having

an optical axis as a center, a middle region located at an outer side with respect to the inner circumference region and surrounded by another circular aperture that is located at an outer side of the circular aperture, and an outer circumference region located at an outer side with respect to the middle region, the aspheric profiles of the inner circumference region and the outer circumference region correcting a spherical aberration with respect to the first optical disk substrate which has a smaller thickness than the second optical disk substrate, a thickness  $t_5$  of the optical disk substrate satisfies the following relationship (10) when the aspheric profile of the middle region is optimized so that the spherical aberration is corrected with respect to the thickness  $t_5$  of the optical substrate, and the outer circumference region is formed with a difference in level corresponding to an integral multiple of the optical path length in the direction of an axis with respect to the inner circumference region,

wherein the objective lens satisfies the following relationships (11) to (13)

$$\begin{array}{ll} 1. & 0 < t_5 < 1.4 & (10) \\ & t_1 < t_2 & (11) \\ & 0.35 < NA_2 < 0.43 & (12) \\ 20 & 0.03 < NA_3 - NA_2 < 0.1 & (13) \end{array}$$

wherein  $t_1$  denotes a thickness of the first optical disk substrate,  $t_2$  denotes a thickness of the second optical disk substrate,  $NA_2$  denotes a NA of the objective lens at the boundary between the inner circumference region and the middle region, and  $NA_3$  denotes a NA of the objective lens at the boundary between the middle region and the outer circumference region.

13. The objective lens for an optical disk according to claim 12, wherein the focal position in which a wavefront aberration of the inner circumference region is minimized and the focal position in which a wavefront aberration of the outer circumference region is minimized are the same when light beams are focused through the second optical disk substrate.

14. The objective lens for an optical disk according to claim 12, wherein the third order spherical aberration component  $S_3$  of the wavefront aberration in the ranges of the inner circumference region and the middle region is approximately 0 when light beams are focused through the second optical disk.

15. The objective lens for an optical disk according to claim 12, wherein the boundary in which the inner circumference region is connected to the middle region does not have a difference in level.

16. The objective lens for an optical disk according to claim 12, wherein the boundary between the middle region and the outer circumference region is provided at the intersection point of the profiles of the middle region and the outer circumference region.

17. The objective lens for an optical disk according to claim 12, wherein both the boundary in which the inner circumference region is connected to the middle region and the boundary in which the middle region is connected to the outer circumference region do not have a difference in level.

18. The objective lens for an optical disk according to claim 12, which is formed by glass molding or plastic molding.

19. An optical head device comprising two light sources, a focusing means for focusing light beams emitted from the two light sources onto an information medium surface through first and second optical disk substrates each having a thickness corresponding to the respective light sources, a light flux separating means for separating light fluxes modulated at the information medium, and a light receiving means for receiving the light beams modulated at the information medium, wherein the focusing means is the objective lens for an optical disk according to claim 1, 7, or 12.

20. An optical information recording and reproducing apparatus recording information on the information medium surfaces of first and second optical disk substrates each having a different thickness, or reproducing information recorded on the information medium surfaces by the use of an optical head device, wherein the optical head device according to claim 19 is used as the optical head device.

21. An objective lens for an optical disk comprising a single lens made of glass and focusing light beams into a point image through first and second optical disk substrates each having a different thickness,

at least one surface of the objective lens being divided into at least three regions by concentric circles having an optical axis as a center, the three regions including a first region including the optical axis and a second region located outermost part are rotationally symmetric aspheric surfaces, and a third region sandwiched by the first region and the second region is a toric surface having the optical axis as an axis of rotation.

22. The objective lens for an optical disk according to claim 21, wherein the third region that is the toric surface is in contact with the second region and intersects the first region.

23. The objective lens for an optical disk according to claim 21, wherein aspheric coefficients of the first region and the second region are different from each other.

24. The objective lens for an optical disk according to claim 21, wherein the toric surface is provided on the surface having a larger central radius of curvature of the lens.

25. The objective lens for an optical disk according to claim 21, wherein the third region is a toric surface obtained by rotating a circular arc with an optical axis as a center, the circular arc having a radius R satisfying the following relationship (14).

$$0.7 \text{ mm} < R < 2.5 \text{ mm} \quad (14)$$

26. The objective lens for an optical disk according to claim 21, wherein the third region is a toric surface obtained by rotating a circular arc with an optical axis as a center, the circular arc having a radius R satisfying the following relationship (15).

$$1.6 \text{ mm} < R < 2.1 \text{ mm} \quad (15)$$

27. The objective lens for an optical disk according to claim 21, wherein the width w of the third region satisfies the following relationship (16):

$$0.02 \text{ mm} < w < 0.04 \text{ mm} \quad (16)$$

28. An optical head device comprising a first light source emitting light beams having a first wavelength, a second light source emitting light beams

having a second wavelength different from the first wavelength, a focusing means for focusing light beams emitted from the first and second light sources onto an information recording medium, a first light receiving means for receiving the light beams having the first wavelength among the reflecting light beams from the information recording medium and a second light receiving means for receiving the light beams having the second wavelength, wherein the focusing means is the objective lens of an optical disk according to claim 21.

29. A mold for molding a lens produced by grinding cemented carbide, a lens molding surface being divided into at least three regions by concentric circles having an optical axis as a center, among the three regions, a first region including the optical axis and a second region located outermost part are rotationally symmetric aspheric surfaces, the third region sandwiched by the first region and the second region is a toric surface having the optical axis as an axis of rotation.

30. The mold for molding a lens according to claim 29, wherein the radius of curvature R of the toric surface having the optical axis as an axis of rotation satisfies the following relationship (17).

$$0.7 \text{ mm} < R < 2.5 \text{ mm} \quad (17)$$

31. The mold for molding a lens according to claim 29, wherein the radius of curvature R of the toric surface having the optical axis as an axis of rotation satisfies the following relationship (18).

$$1.6 \text{ mm} < R < 2.1 \text{ mm} \quad (18)$$

32. A method for working a mold for molding a lens, comprising: grinding a lens molding surface divided into at least three regions by concentric circles having an optical axis as a center, among the three regions, a first region including the optical axis and a second region located outermost part being rotationally symmetric aspheric surfaces, the third region sandwiched by the first region and the second region being a toric surface having the optical axis as an axis of rotation by the use of a diamond grindstone, wherein a radius of the diamond grindstone used for the grinding work is the same as or smaller than the radius of curvature of the toric surface.

33. The method for working a mold for molding a lens according to claim 32, wherein the radius R of the diamond grindstone satisfies the following relationship (19):

$$0.7 \text{ mm} < R < 2.5 \text{ mm} \quad (19)$$

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34. The method for working a mold for molding a lens according to claim 32, wherein the radius R of the diamond grindstone satisfies the following relationship (20):

$$1.6 \text{ mm} < R < 2.1 \text{ mm} \quad (20)$$

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35. A profile measuring device comprising a precision stage, a controller for controlling the precision stage, a length measuring means, a means for inputting design profile data, and a means for outputting a difference between the design profile data and measuring data, wherein as the design profile data, a first rotationally symmetric aspheric surface is used in the region where the distance from the optical axis less than the radius  $h_1$ , a second rotationally symmetric aspheric surface is used in the region where the distance from the optical axis is not less than the radius  $h_2$ , and a toric surface having the optical axis as a rotationally symmetric axis is used in the region between the radius  $h_1$  and the radius  $h_2$ .

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